Reference to past time

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Reference to Past Time[1]

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1 PRELIMINARIES

1.1 Introduction

Lyons (1977, p. 637) has defined deixis as 'the location and identification of persons, objects, events, processes and activities being talked about, or referred to, in relation to the spatiotemporal context created and sustained by the act of utterance . . .'. The present paper examines the linguistic apparatus of tense and other related categories which is used to accomplish such deixis to events and states of affairs in the past. In particular, it is concerned with the precise way in which such adjuncts as *when* clauses do sustain, and indeed change, the spatiotemporal context to which these categories refer.

The problem in formulating the semantics of time reference has always been the extraordinary ambiguity or non-specificity apparent in the linguistic categories that are involved. It seems as if a wide variety of different meanings[2] are distributed rather haphazardly among a handful of linguistic devices. For example, a simple English clause in the past tense, such as

(1) John played 'Cherokee'

may refer to a single occasion of playing, either incomplete or completed, or to a period of repeated playing of the tune. It may also refer to a rather more indefinitely extended period of habitual playing of the tune, or even to the instant with which its playing began. These various meanings may be brought out by the inclusion of different time adverbials, such as *for a few minutes, in a few minutes, for ten hours, in those days,* and *at half past nine*, respectively. (Temporal description is of course only one class of meaning carried by past tense. Others are *oratio obliqua* and counterfactuality. Only the purely temporal meanings will be considered here.) The meanings of time adverbials and subordinate clauses such as *when* and *while* clauses, which will be termed 'time adjuncts', are themselves also typically ambiguous. For example, two events related by a complex sentence involving a *when* clause may either be

simultaneous, or sequential, as in

(2a) When she took my queen, she gave me check.
(2b) When she took my queen, I took hers.

Of course, such protean shifts of temporal description as those ascribed to (1) may also occur in the complex sentences typified by (2). In the following sentence the main clause tends to undergo a change in character from the basic stative meaning of clauses involving the verb to *know*, to refer to the instantaneous event with which the state of knowing begins.

(3) When he left the party, I knew something was wrong.

Such context-dependent shifts in temporal descriptive meaning occur with great facility, and make the semantics of tense, mood, the auxiliaries, and the time adjuncts particularly hard to capture. They also mean that the literature of this area is unusually fraught with examples of unnoticed ambiguities, and of conflicting and uncertain intuitions. Moreover, while this vast literature describes the varieties of meaning that each category may convey, it has generally proved more difficult to show why just those particular functions rather than some other arbitrary collection, should have been brought

	When John left, . . .	When the band played, . . .	When the band was playing, . . .	When John had left, . . .
. . . , Fred left	| ——— | →	|/////| ——— | →	|/////| ——— |	|/////| ——— |
. . . , Fred danced with Alice.	| ——— |//| →	|/////| ——— |/////| →	|/////| ——— |//|	|/////| ——— |//|
. . . , Fred was dancing with Alice.	| ——— |/////|	|/////| ——— |/////|	? |/////| ——— |/////|	? |/////| ——— |/////|
. . . , Fred had left.	| ——— |/////|	|/////| ——— |/////|	|/////| ——— |/////|	?? |/////| ——— |/////|

Figure 1 Various temporal relations that can be conveyed by complex sentence including *when* clauses depend upon the verbs and auxiliaries of the two clauses

	While the band played, . . .	While the band was playing, . . .
. . . , Fred left	? |/////| ---------- |	|/////| ---------- |
. . . , Fred danced with Alice.	|/////| ---------- |/////|	|/////| ---------- |////|
. . . , Fred was dancing with Alice.	|////| ---------- |/////|	|////| ---------- |////|
. . . , Fred had left.	? |////| ---------- |////////	? |////| ---------- |////////

Figure 2 Various temporal relations that can be conveyed by complex sentences including *while* clauses

together under a single linguistic roof. As Bennett (1975) has pointed out, it is essential for a semantic theory to meet this latter criterion.

In this paper, it is proposed that certain apparent ambiguities of tense, the progressive and perfect auxiliaries, and *when* and *while* time adjuncts in English can best be understood as ambiguities of the process of reference, rather than of sense or semantics, and that, given an appropriate account of the mechanism of reference, some apparently diverse meanings conveyed by these categories can be seen to be derived from a single sense.

Some impression of the complexity of the interactions of these categories can be gained from Figures 1 and 2, where tables are presented showing temporal relations typically expressed by *while* and *when* in complex sentences. In each cell of the tables, the temporal extent defined by the subordinate clause appears above a line representing the dimension of time. The temporal extent defined by the main clause appears below. Where the relation is unspecific, an arrow represents the direction of variability. Where the sentences in a cell are odd or anomalous, the anomaly is indicated by one or more question-marks.

1.2 Reference

It has often been pointed out that tense is anaphorically and deictically referential in character (McCawley, 1971; Partee, 1973; Isard, 1974; Lyons, 1977). That is, just as the anaphoric pronoun *he* demands an antecedent in

the preceding conversation, so, as McCawley points out, sentences like (1) must have an antecedent past time for their tense to refer to. If no such reference time has been established in the preceding conversation, say by a *when* clause such as *When I was at Jim's last night*, . . . , then (1) will be unacceptable.

It is arguable that the most successful theories of reference to date are those theories which have been expressed as or exemplified by computer programs of which Winograd's (1972) was an early example. Winograd's program could carry on a 'conversation' with a human operator concerning states of affairs in a simulated universe of discourse representing a table-top upon which a number of child's blocks were to be found. The program's principal capabilities were to obey orders concerning this 'Blocks World', and to answer questions both about its current state, and about past situations that had occurred in the course of the conversation. The orders and questions could involve a wide range of expressions referring to objects in the world, including quantified expressions, such as *the box, a big red pyramid, all blocks, any cube*, and so on. Some of these references could be anaphoric in nature. For example, an expression like *the block*, in the context of a simulated world containing several blocks, achieves its reference by causing the recent conversation to be examined for mention of a suitable object, as do more purely anaphoric expressions such as *it* and *that*.

Winograd's program also allows a simple kind of reference to events that have taken place during the conversation. For example, it can answer questions such as

(4) Did you pick up anything red while you were building the steeple?

As an account of time reference, it is greatly simplified with respect to the problems outlined in the introduction to this paper, and his way of handling questions like (4) is rather different to the procedures that will be suggested here. However, the present theory shares the feature of being embodied in a computer program, and also exploits the clear relation that such programs express between the semantics of an expression and the context in which it is used, in order to express both the sense and the reference of tense, the progressive and perfect auxiliaries, and the time adjuncts.

1.3 The nature of temporal descriptions in English

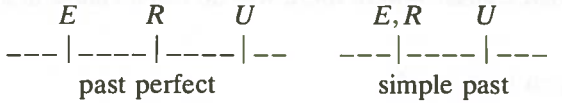
It has frequently been noted that many languages embody a parallel between concepts of space and of time. In English, nearly all locative prepositions are also temporal prepositions, and the concept of deixis has been applied to time as well as to space. In particular, tense is a quasi-spatial, deictic category (cf Lyons, 1977; Miller & Johnson-Laird, 1976).

The classic localist account of the nature of tense and time reference is that

of Reichenbach (1947). According to his scheme, the distinctions of tense are distinctions between the relationships of three points along a time-line. These three points are the utterance time, or time of speaking (U), the reference time (R), and the event time (E). For example, the past perfect in sentence (5) is held to describe the event of John's winning as being in the past with respect to a reference time which is itself in the past with respect to the time of utterance:

(5) John had won.

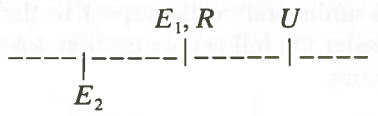
By contrast, a simple past tense conveys an event time simulataneous with the reference time, both being in the past with respect to the utterance time. Such relationships are conveniently represented pictorially, as in (6):

(6)


Reichenbach's scheme was intended, in part, to explicate the meaning of time connectives, such as *when*. For example, the meaning of

(7) When Fred arrived, John had won

depends on the identity of the reference points in the two clauses, and may be represented diagrammatically as follows, where E_1 represents Fred's arrival and E_2 John's winning:

(8)


Reichenbach (1947) embodied this behaviour of *when* clauses in the principle of the 'positional use of the reference point'.

Reichenbach's scheme neatly expresses the quasi-spatial and deictic nature of tense and time reference and many subsequent theories of tense and the auxiliary system have built upon its foundation (e.g. Bull, 1963; Isard & Longuet-Higgins, 1971; Smith, 1975, 1978; Hornstein, 1977). In particular, Isard (1974) considerably extended the idea to encompass the semantics of conditionals and counterfactual conditionals, of modal verbs, and of *when* relative clauses. The current paper stems directly from his work on the last of these categories.

1.4 Tense and time reference

The task for Isard's (1974) program was to answer questions, posed in type-written English, concerning the moves in a game of tic-tac-toe, or noughts-

and-crosses, which it played with its operator. Typical questions were

(9a) Could you have taken square four when I took square five?
(9b) If I had taken square four when I took square five, what would you have done?

The *when* clause in such questions was evaluated first, to yield a new referen for the past tense marker—in the above cases, by searching for that situatior in the game's history at which the operator took square five, or for the situation immediately following. (Counterfactual conditionals and moda verbs were handled using simulated possible states of play, in addition to the single Reichenbach line of factual time.) Once this had been done the mair clause could be evaluated solely by examination of the situation that had been identified by the *when* clause. Where there was no *when* clause in a question for example

(10) Could you have won?

the program would take the reference time to be the one most recently established.

In expressing the role that *when* clauses play in setting up a tempora referent, Isard's account goes considerably beyond Reichenbach's. It is no enough to say, as he did, that the reference times of main and subordinate clauses must coincide. The *order* in which subordinate and main clause are evaluated is crucial for the language understander, since natural language expressions are typically extremely ambiguous with respect to the events to which they refer. For example, consider the following question, asked about a party at which the hearer was present:

(11) When the band played 'Autumn Leaves', did Arthur dance with Alison?

There may have been many occasions on which Arthur danced with Alison In answering the question, the order in which the two events are considered makes no difference, *once the particular events in question have been identified*. But in order to identify the particular instance in question of Arthur's dancing with Alison, it is essential to first identify the period of the band's playing the tune in question, and only then to search for an instance of the main clause event in that temporal vicinity. (This will be necessary if further questions about this *particular* instance are to be answered, for example.) It is in explicating these pragmatic aspects of *when* clauses that the computational account can be claimed to add something to the logic-based accounts of Reichenbach and his direct descendants.[3]

It was a virtue of Isard's program that its extremely circumscribed universe of discourse allowed him to tackle several difficult problems in the semantics of tense, mood, and aspect. Nevertheless, it is inevitable that certain idiosyn-

cracies of the world of tic-tac-toe games makes his account less than general. In particular, the fact that the only events that can be discussed are instantaneous moves of the game, and the fact that only one of these events can occur at a time, mean that a great deal of the semantics of connectives like *when* and of sentences in the perfect, and all of the semantics of *while* and of progressive sentences, cannot be illustrated. Moreover, as he pointed out himself, his method of resolving the ambiguity of *when* clauses, as between the 'simultaneous' and 'sequential' meaning, exemplified by sentences (9a) and (9b), was *ad hoc*.

1.5 'Events' and 'situations'

The distinction between instantaneous events and those which occupy a period of time is only the most obvious of those which are made more or less explicit in natural languages. Many linguists and philosophers have been concerned to enumerate the varieties of temporal or 'aspectual' event-descriptions that are distinguished in English, some of which were mentioned in passing in the introduction to this paper. In particular, Vendler (1967), working in a philosophical tradition that includes Ryle (1949) and Kenny (1963), classified English verb-groups into four temporal categories. He derived his classification by observing restrictions upon the co-occurrence of the verb-groups with time-adverbial phrases, such as *in an hour* and *for an hour*. More recently, Verkuyl (1972), Dowty (1972, 1977, 1979), Heinamaki (1974), Bennett (1975), Comrie (1976), Steedman (1977), and Ritchie (1979) have elaborated this basic scheme.

Many of these authors have pointed out that few verbs fit neatly into a single one of these temporal categories. Indeed, most verbs, whatever their 'core' or basic temporal category, can be made to take on *any* temporal category by an appropriate choice of auxiliary or adverbial, as in example (1). Hence, as Verkuyl (1972) argued, these categories should be regarded as classifications of whole propositions, rather than of verbs. It will therefore be important to bear in mind throughout the discussion below that the temporal character of a proposition whose verb we regard as bearing a certain core temporal category may without warning take on a quite different character. While many of the distinctions drawn by Vendler and his followers, such as that between periods with and without conclusions, will not be treated here (but cf. Steedman, 1977), the way that instants can become periods of intermittent repetition of the core instant will be treated. One basic distinction of temporal character will be very frequently drawn upon. A distinction will be drawn between 'events' and 'situations'. The former category includes all definite instants and periods of activity, subsuming in particular Vendler's categories of 'achievements', 'activities', and 'accomplishments'. The latter category includes Vendler's 'states', but also includes sentences bearing progressive and perfect auxiliaries. (McCawley (1971) and Longuet-Higgins

(1973) have pointed out the similarities between such verb groups and statives.) The distinction is related (but not identical) to the durative/non-durative distinction of Heinamaki (1974) and the point/interval distinction of Ritchie (1979).

1.6 Representing episodes and events

A computer program is being developed that is to answer a wide variety of questions involving the categories discussed above. Its universe of discourse is the changing state of affairs on a computer 'operating system'. An operating system is itself a program which has the role of overseeing the simultaneous use of a large computer by a number of human users. The users share certain resources, such as printers and paper-tape readers. Apart from the fact that only one person can use such a resource at a time, the users are free to pursue their activities, such as editing and running their programs, at the same time. It should be stressed, however, that the present program uses a simplified *simulation* of the passage of events in such a system.

The program is to answer questions involving tense, the progressive and perfect auxiliaries, time adverbials and time adjuncts, concerning the course of events on an operating system, much as a witness in a courtroom or in the closing chapter of a detective story might be questioned in detail concerning the precise relation in time of events at the scene of a crime. Such a universe of discourse is considerably more complex than both the Blocks World and the tic-tac-toe world of Winograd and Isard. At the time of writing only the semantic and referential mechanisms have been developed. The syntactic problem of producing the semantic representations from questions posed in English will not be treated here.

The first problem that must be solved in constructing such a program is that of selecting a suitable representation for the history of the universe of discourse. There is no doubt that a simple predicate logic can express the state of each element of the operating system world at each instant of its history, and be used to infer the truth of temporal relations between events in that history. The program employs what amounts to such a logic, embedded in a subset of the POPLER programming language (Davies, 1973) which is itself a descendant of Hewitt's (1969) PLANNER. PLANNER and its descendants can be regarded as theorem provers in which the number of axioms has been reduced at the expense of increasing the number of inference rules (Davies and Isard, 1972).

However, there is still a serious problem with such a representation of episodes in the operating system world—that is, a logic (albeit one of a rather unfamiliar kind) representing the history of the operating system world in a body of formulae and a number of inference rules. The problem arises from the fact that a body of formulae in a logic is essentially *unordered* and *unstruc-*

tured. That is to say that if you are searching for a particular one, you simply have to go through the lot until you find the one you want, or until there are none left. Everything that is known about 'episodic memory', or memory for events, including our intuitions about what happens when we answer questions involving *when* clauses and the like, suggests that our memory of events is very highly structured, and that it is in fact linearly ordered, by analogy with the temporal sequence that it represents. Moreover, it has already been remarked, in considering Isard's model, that it is of the essence of complex sentences involving *when* clauses that the *when* clause be considered *first*, and that the tense of the main clause be interpreted in anaphoric relation to the referent thus established. However, this obvious intuition about the process of answering questions about episodes is not captured by the kind of model that we have considered so far. Consider, for example, the question

(12) When your son was born, was it snowing?

Having identified the reference time when the child was born, we would still have to examine every formula, including those referring to all occasions on which it was snowing, even though most of these can immediately be rejected as not referring to the reference instant in question. Since we have to examine them, we might as well have found all occasions on which it was snowing *first*, and *then* found the reference time. Simply on grounds of efficiency, it would be sensible to go for a different kind of representation, in which the establishment of the reference time restricts the search to some particular subset of the formulae.

Such a representation can be achieved by structuring the formulae into a linear sequence of bundles, each bundle consisting of just those formulae which define successive situations. Stephen Isard (1974) used a very simple version of such a representation. The successive situations were the successive states of the tic-tac-toe board. The description of any given situation consisted in effect of a set of facts defining the ownership of the squares by the two parties. And since each successive state of the game only differs from its predecessor and successor in respect of the ownership of a single square, all that really needed to be kept was an ordered sequence of *moves* of the game: from these, any given situation could be constructed. Such a representation has an 'analogue' character, directly representing and exploiting a property of the world which goes in the literature by the name of the 'Frame Property'—that is, the fact that there are continuities between successive situations in the real world. This aspect of the representation clearly effects a saving in the number of facts that need to be stored. In such a miniscule world the saving may not be too important, but it will be crucial in representing the more complex episodes of the operating system world. (It was also essential to Isard's program's understanding of conditionals and modals, as called on by questions like the following:

(13) If I had taken square three when I took square four, what would you have done?

The same expedient was adopted by Winograd.)

The current program exploits the advantages of this kind of representatio in a similar way. As in Isard's program, an ordered list of events that hav affected the state of the world is kept. And again, a representation of the stat of the world at a given time is maintained, as a set of formulae. Also, th effect of a time adjunct such as a *whole* or *when* clause, is to cause this worl model to be set to a certain situation in the past. The main clause is the interpreted with respect to that situation. However, apart from this basi similarity to Isard's program (and to some extent to Winograd's) it turns ou that the problems associated with handling the kinds of event description that have been described in the introductory sections require a considerabl elaboration of the basic scheme.

1.7 Representing period events

In setting up a representation of the kind described in the last section, the first problem is to decide how to represent periods, and how to represent thei use as referents, as in

(14) While my program ran, how much CPU time did I use?

Since the representation of the history of the episode is to consist solely o *changes* in the state of the world, and changes of state are by definitio instants, the solution to the first part of the problem is simple: we represen periods in the history by noting the instants with which they begin and end. For example, a very much simplified 'history' of a session is illustrated i Figure 3.

The figure represents an ordered sequence of 'bundles' of proposition each defining a number of simultaneous instantaneous changes to the state o the universe of discourse. Each proposition is represented as a data structure enclosed in square brackets, such as

(15a) [[INSTANT START PERIOD] ANN PRINT FILE1],
(15b) [[INSTANT] BETTY LOGIN].

Such data structures correspond to atomic formulae in more traditional logical inference systems. Each begins with a substructure identifying its type (that is whether it is a simple instant like someone logging into the system o the start or end of a period). The type is then followed by a string of symbols which define the particular nature of the event. It will be observed that the history in question is a somewhat artificial one: there are rather a lot of events that coincide exactly in time. It has been set up in this way deliberately, to

```
1 – [[INSTANT] ANN LOGIN]
    [[INSTANT] ALF LOGIN]
    [[INSTANT] ARTHUR LOGIN]
    [[INSTANT] ALISON LOGIN]
    [[INSTANT START PERIOD] ARTHUR TALK TO ALISON]
    [[INSTANT START PERIOD] ALF EDIT FILE1]
    [[INSTANT START PERIOD] ANN PRINT FILE2]

2 – [[INSTANT] BETTY LOGIN]
    [[INSTANT] BILL LOGIN]
    [[INSTANT] BERT LOGIN]

3 – [[INSTANT STOP PERIOD] ARTHUR TALK TO ALISON]
    [[INSTANT] CATHY LOGIN]
    [[INSTANT] CHARLES LOGIN]

4 – [[INSTANT] ALF LOGOUT]
    [[INSTANT STOP PERIOD] ANN PRINT FILE2]
    [[INSTANT STOP PERIOD] ALF EDIT FILE1]
    [[INSTANT START PERIOD] ARTHUR TALK TO ALISON]
    [[INSTANT START PERIOD] ANN PRINT FILE3]

5 – [[INSTANT STOP PERIOD] ARTHUR TALK TO ALISON]
    [[INSTANT STOP PERIOD] ANN PRINT FILE3]
    [[INSTANT START PERIOD] CATHY EDIT FILE4]
    [[INSTANT] BILL LOGOUT]

6 – [[INSTANT] BETTY LOGOUT]
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Figure 3 A simplified history of an episode in the operating system world

allow full scope for the examples that are to follow without making the history too complex.

Such a representation of the history is not unlike that used by Isard, apart from the fact that more than one thing can happen at a time. However, it is clear that in order to represent the temporal reference *periods* established by utterances like (14) it is no longer possible to identify the temporal referent with a single instantaneous situation or state of the world. Instead, the temporal referent must correspond to a whole segment of the time line, from the start to the end of the reference event, in this case *my running my program*. Thus the temporal referent itself must be distinguished from the model of the state of the world at any given instant. For the moment, it will suffice to think of the temporal referent established by (14) as a pair of numbers defining the extent of the reference 'windows' on the time line.

It should be noted in passing that although the history includes a repeated occurrence of Arthur talking to Alison, and in English these events can be referred to collectively as a repeated event of the kind discussed in the introduction, the fact that instant 1 is the start of such a repitition is *not* marked explicitly in the history. Such instants must be *inferred* in a way to be discussed below. Thus, although instants are the primitives of the system, not all

instants are primitive. Certain other kinds of event also are not directly represented in the history—for example, the instants at which the system prints messages to a user that have been left for him by the other users: there is a general rule of inference which says that people get their messages when they log in to the system, to be used in answering questions like

(16) Has Fred received the message that I sent him?

1.8 'Simple' past tense

As long as questions about the operating system world do not involve progressive or perfect auxiliaries, the basic apparatus developed by Stephen Isard is quite adequate, despite the extension to events occupying a period of time. Consider for example

(17a) When Betty logged in, did Bert log in?
(17b) When Betty logged in, did she get my message?

As before, the referent-setting *when* clause is evaluated first, and it seems to set the context either to the instant of Betty's logging in, or to the instant just after that. And again, the main clause is evaluated with respect to that reference time.

While clauses involving periods behave in a similar manner, at least when they do not involve the progressive auxiliary, as in

(18) While Ann edited her file, did she use the printer?

The above *while* clause sets a reference period as the context for the main clause, and behaves in every respect like a *when* clause. For example, the tense of the following supplementary question has the same 'pronominal' reference to the period of Ann's editing.

(19) How much processor time did she use?

A slight complication is introduced when a *when* clause involves a period. At first glance the following question seems to ask much the same as (18)—that is, whether the two events were coextensive.

(20) When Ann edited her file, did she use the line printer?

However, this is not generally true of *when* clauses involving periods. Consider

(21a) When Ann edited her file, did John use the line printer?
(21b) When Ann ran her program, did John sign off?

In the first of these it is not necessarily the case that editing and printing were co-extensive, and in the second, the two events *cannot* be co-extensive, since one is a period, and the other an instant.

The behaviour of these sentences is due to an aspect of questions with *when* clauses that has not been made explicit up to now. A distinction was drawn using examples such as (2) between a 'simultaneous' and a 'sequential' relationship between events related by a *when* adjunct. However, the latter relationship would be better described as 'con-sequential'. Questions involving the so-called sequential relation invariably implicate or presuppose a consequential effect of the event in the subordinate clause upon that in the main clause, such as *enabling* or *causing* its occurrence. It is this meaning that is understood in all of the above three questions. They take on their particular meanings because one knows, for example, that if someone signs off *because* someone else runs a program then they may do so at some time during the run, but if someone uses a printer as a consequence of running their own program, then they tend to start at the same time and continue until they stop. The same ambiguity between questions about causation and simulaneity arose in Isard's (1974) tic-tac-toe world. The apparent difference in reference between

(22a) When I took five, did you take seven?

and

(22b) When I took five, did I win?

was handled by Isard simply on the basis of whether the subjects of the two clauses were the same or different. As he pointed out, this was unsatisfactory. In particular, it would give an inappropriate result for a question like

(23) When John logged in, did he get a message?

—where the two events are presumably consequent rather than simultaneous, despite having the same subject. The question of causal or consequential interpretations of time adjuncts is a complicated one, and will be discussed later in the context of the perfect auxiliary, whose meaning is intimately bound up with ideas of intention and cause. The question of exactly what it means to describe two events as standing in this 'consequential' relationship will also be deferred until then.[4]

While does not produce any ambiguity between a temporal meaning and a consequential one. Indeed, it seems expressly to *exclude* the idea of a logical connection between the two events: if you have reason to suppose that Ann's editing *caused* John's use of the printer, then you should ask a question like (21a), rather than the corresponding *while* question. The program represents a *while* or *when* question as a sequence of three 'goals' or steps of inference. The first of these goals is to establish a reference interval as the value of a variable *ref*, by searching the entire history of the episode for examples of the event or situation in the subordinate clause. The second stage is to search the history within that interval for any example(s) of the main clause event or

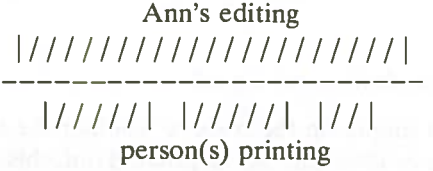
situation. The temporal extent thus defined becomes the value of another variable, *anaphor*. The third goal is to check that the two times defined by *ref* and *anaphor* stand in the relation specified by the type of adjunct and main clause. For example, the question

(24) While Ann edited her program, did anyone use the line printer?

should only be answered affirmatively if the two times are co-extensive—that is, if the main clause event lasts throughout the reference interval defined by the subordinate clause.

The only constraint that has been placed on the search for the main clause events in the above example is that the search be conducted within the bounds of the reference time. Hence it may well happen that more than one instance will be found matching the main clause description. For example, in answering the last question, it may be the case that someone used the printer several times. These states of affairs can be represented graphically by the same kind of extension of Reichenbach's time-line diagram that was used in Figures 1 and 2.

(25)



In such a context, the simple procedure outlined above behaves in a manner which is strikingly similar to the way that hearers seem to behave with respect to the systematic ambiguity in English between single and repeated events. That is, the program will find *all* the instances within the reference period, whether there is one or there are many. These are collected into one compound event description. Once the period that has been found has been proved to be co-extensive with the reference time, as the *while* demands, the program can answer the question, either with a list of the people who have used the printer, or with a single name, whether or not this person's action was repeated. (Of course, in the case of a repeated action, a human question answerer might well judge it to be helpful to the questioner to mention this fact, by replying 'Jane did, *several times*'. However, the decision to give such a helpful amplification would depend upon inferences concerning the likely purposes of the questioner in obtaining the information. Such inferences are not the concern of this paper (but cf. Steedman & Johnson-Laird, 1978). The important goal for the program is merely to obtain the factual information from which such replies might be constructed. Presumably, a language which marks iterative aspect would only differ in that the last goal of the sequence, corresponding to the relationship established by the subordinate clause, would explicitly specify either a compound repeated event or a simple event.

Perhaps a more important respect in which the program appears to correspond to the human speaker's treatment of this distinction is in the way it often *does not* consider the ambiguity. If the program is asked the same question in a context in which, although many people used the line printer, only one such occasion occurred within the scope of the reference period, then it will simply never consider the possibility that the iterative meaning of the question is intended, because its search for the main clause event never proceeds beyond those confines. This too seems to be a natural treatment of the distinction. Consider the case where two human conversants are discussing a party which one of them attended and the other asks

(26) While you talked to Mary, was the band playing?

If the band played several tunes in the relevant period, as part of a longer period of intermittent playing, the events can be represented by the familiar sort of diagram, thus:

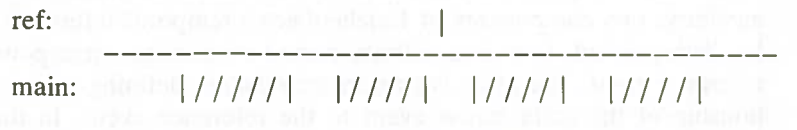
(27)

In such a context, the non-iterative meaning of the main clause does not seem to arise. By contrast, if the question is

(28) When Jane arrived, was the band playing?

then it is the iterative meaning that does not seem to arise. In particular, if the band wasn't actually engaged in playing at the relevant time, as in the diagram below, it does not seem possible to answer 'Yes' to the question, at least without giving further explanation, even if its silence merely represents a temporary lull in a period of repeated playing.[5]

(29)



Similar remarks can be made about the 'inchoative' aspectual interpretation of past tense, in which a clause, such as one of the interpretations of sentence (1) in the introduction to this paper, denotes the beginning of the period to which it 'basically' refers. However, further discussion of these questions will be deferred until the discussion of causation, with which they are considerably involved.

To summarize: a simple procedure for answering questions about an episode has been presented. It has been argued that the sense of such time connectives as *while* and *when* can be naturally expressed within such a framework, and that certain ambiguities of tensed sentences, notably so-

called iterative aspect, can be regarded as a natural consequence of the pro cess of establishing reference, rather than as ambiguities of sense. In the nex sections, this argument is extended to sentences including progressive an perfect auxiliaries.

2 THE PROGRESSIVE

2.1 During, throughout, and the progressive auxiliary

While clauses which include the progressive auxiliary verb *be* also function t set a temporal reference point for succeeding main clauses, like those wit simple past tense. Thus the following sequence is directly analogous to th earlier examples:

(30a) While Anne was editing her program, did Betty log in?
YES.
(30b) Did Alf log in?

As before, the supplementary main clause (b) is understood to refer to th reference time established in the previous question. However, the nature o this reference time is rather different from that of a definite reference instan or period. For, of course, it is not necessarily the case that Betty's and Alf' logging in to the system should have occurred at the *same* instant durin Ann's editing—merely that they both did it at *some* such instant.

The notoriously indefinite character of the progressive (Geis, 1970) is no easily captured in the time-line diagrams of Reichenbach's account, and it i not surprising that those whose work stems most directly from Reichenbach' (Smith, 1975, 1978; Hornstein, 1977) have not treated the topic in depth (bu cf. Bull, 1963).

In order to capture the semantics of *while* clauses including the progressiv auxiliary, two components of Reichenbach's temporal reference point mus be distinguished. One is a definite period or instant, corresponding to th reference *event*. The other is a reference *relation*, defining the temporal rela tionship of the main clause event to the reference event. In the case of temporal referent established by a progressive time adjunct, as in (30) above the relation of the main clause event to the reference event is that of bein *included* in its scope, and it is this relation which is understood to persist an be available for subsequent simple clauses such as (30b), rather than the tim of the main clause event of (30a).

The separation of the step in the computation at which the reference even is found from that at which a particular relation between the two events i tested was made in the earlier account of simple past tense, although it onl becomes crucial to make this separation in dealing with the auxiliaries. Th separation amounts to a distinction between two components in Reichen

bach's reference time *R*, as between the reference *event* and the reference *relation*. It is not the same as the similarly-named distinction drawn by Smith (1975), which is rather a translation of Reichenbach's scheme into componential semantic terms. It is, however, related to distinctions drawn by Ritchie (1977, 1979). The two temporal relations that are concerned in the contrast between simple past tense and the progressive are those expressed in English using the prepositions *throughout* and *during*, respectively.

The existing apparatus might seem to be adequate to handle progressives as well as simple tensed clauses, simply with the addition of the procedure to test the relation of inclusion as well as that for testing coextension. However, once the effect of progressive main clauses is considered, it becomes clear that some extensions to the theory are necessary. In particular, the program's model of the state of the world needs further elaboration.

Consider the question

(31) While I printed my files, was Ann editing her program?

—which can be represented by the usual sort of diagram, as follows:

(32)

As matters stand so far, the only things that are present in the machine's representation of a state of affairs in the world are the instants which compose the history of the episode, such as the one laid out in Figure 3. Since the basic procedure for answering questions about events is to conduct a search for the main clause event *within* the window defined by the reference event, and the instants with which the main clause event begins and ends do not fall within that window, the existing apparatus will not allow the program to answer such questions.

The solution lies in elaborating the program's representation of the state of the world at a given instant. The program represents data about period events that are in progress in a body of facts, or a 'data-base', that describes the state of the world at any given instant, perhaps using atomic formulae of a form like the following

(33) [[IN-PROGRESS PERIOD] ANN EDIT PROGRAM3]

Of course it would be possible simply to include such facts among the 'bundles' of instants in the history of the episode. However, with the addition of a few simple 'housekeeping' procedures it is easy to make the program add these facts automatically to a representation of the state of the world at any given instant as it searches up and down the history. The apparatus for maintaining such models is well established, and in fact is provided ready-made in

[TIME 6]
[[STATE] ANN BE PRESENT]
[[STATE] ARTHUR BE PRESENT]
[[STATE] ALISON BE PRESENT]
[[STATE] BETTY BE PRESENT
[[INSTANT] BETTY LOGOUT]
[[STATE] BERT BE PRESENT]
[[STATE] CATHY BE PRESENT]
[[STATE] CHARLES BE PRESENT]
[[IN-PROGRESS PERIOD] CATHY EDIT FILE4]

Figure 4 The state of the world at time 6 of the history shown in Figure 3

POPLER, in the form of its version of PLANNER 'antecedent theorems' The same device is used for certain other varieties of situation, such as a individual's being present on the system. The data base representing the stat of affairs at time 6 in the history represented in Figure 3 is shown in Figure 4.

Using such a representation of states of affairs in the operating systen world, questions like (30) can be answered quite simply; once the referenc period in that question has been found, the representation of the state o affairs at every instant in it will express directly the fact that the main claus event is in progress.

The above representation of the progressive is quite compatible with th apparatus described earlier for establishing temporal referents. Since th standard procedure of searching through the episode for instances that matc the pattern of the subordinate clause collects *every* such instance, the sam process applied to a progressive such as the one in (34), below, will simpl collect together all instants at which the corresponding progressive is in forc in a manner precisely similar to the way in which an iterative or repeate event is found:

(34) While Ann was running her program, did Fred log in?

And the period that this process delivers will be of exactly the same extent a the corresponding question with a simple past tense subordinate clause. Th difference lies in the reference *relation*, rather than the temporal extent of th reference *event*. It is perhaps worth noting in passing that a number of puzzl ing facts about the relationship between the progressive and simple tenses ar explained by such a mechanism. The time adjuncts *while she was playing* an *while she played* only differ in the reference *relationship* that they establish and this relationship is only investigated as the last step in computing th meaning of sentences that include them. Hence it is only investigated *after* th events in question have been identified. It is therefore not surprising that while the second of the two following statements is strictly speaking anomal ous (since John's leaving cannot have been co-extensive with the playing o

the sonata), nevertheless informants are very inconsistent in their judgements.

(35a) While she was playing the sonata, John left the room.
(35b) ?While she played the sonata, John left the room.

Secondly, just as the theory of reference explains why languages are free to vary as to whether they explicitly mark iterative aspect, so it explains why they are similarly free with regard to the marking of imperfective aspect. If the reference relation is distinguished in some other way, there is no practical difference between the progressive and simple tense. (French is an obvious example of a language which has in general no explicit mark of imperfective aspect.) The rule that determines the reference relationship used in the third step of the procedure for *while* is as follows:

(36) When the subordinate clause is of the 'event' variety, the relation is one of co-extension. When the subordinate clause is of the 'situation' type, the relation is one of inclusion.

It will be noted that this procedure allows the context to resolve the ambiguity between simple and iterated events in exactly the same manner as was described before for simple past tense.

To summarize this section: by addition of a data base, (of a kind quite standard in the literature of Computational Inference), which represents the state of the world at any given instant in its history, and by distinguishing two components of Reichenbach's concept of reference time, it is possible to extend the model to cope with certain uses of the English progressive,[6] whilst preserving the efficiency of the earlier representation, and also preserving its natural handling of the disambiguation of iterative and simple meanings of event descriptions. In the next section a further extension to deal with the perfect is considered.

3 THE PERFECT

3.1 Causation and consequence

Of all the categories under discussion here, the perfect is the most complex. Any attempt to characterize the perfect and past perfect in purely temporal terms, as 'past in present' and 'past in past' does not do it justice, whatever the virtues of Reichenbach's original scheme and Smith's (1975) translation of it into componential semantic terms. Unlike the uses of the progressive discussed above (but cf. note 6), the relations that it denotes are not purely temporal. It is not the case that *He had arrived at noon* means no more than *He arrived before noon*. The most basic meaning of the perfect appears to be to

do with the idea that the *consequences* of the event in question are in force a the (past or present) reference time. Thus, to felicitously say (37) below, it i not enough that John's arrival be in the past with respect to the reference tim (which is in this case the time of utterance). The consequences of John' arrival, in particular his *being present*, must *also* hold at that time.

(37) John has arrived.

All of the many uses that have been distinguished for the English perfec (discussed by Comrie, 1976) appear to partake of this basic idea. Indeed, i seems likely that its temporal meaning may be merely secondary to the 'con sequent state of affairs' meaning, and stems from the fact that it is in th nature of consequences to succeed their causes in time. (Such a proposal als has the merit of making auxiliary *have* seem closer to other causative uses o the verb, in sentences like *She had it stuffed, I have a bone to pick,* and *He ha to put a finger in the dyke*.)

Much of the complex behaviour of the perfect can be explained in terms o this analysis. Sentences with auxiliary *have*, unlike progressive and simpl tensed sentences, do not at first glance appear to behave in at all the sam manner in time adjuncts as in main clauses. So, whereas (37) refers to th state of affairs consequent upon John's arrival, the perfect in (38a) seems a first glance to have much the same effect as the simple past tense of (38b)

(38a) When the guest of honour had arrived, the speeches began.
(38b) When the guest of honour arrived, the speeches began.

However, *two* meanings of *when* clauses have to be distinguished, one i which *when* can very roughly be paraphrased by *just as*, and another whic has been rather vaguely related to the idea of causation and consequence, an in temporal terms seems to mean *just after*. It is only with respect to th *second* meaning of *when* that the above sentences are approximate para phrases. In fact, *when* with the perfect can *never* mean the same as *just as* Thus, the following sentences are not paraphrases, and the second is anomal ous, because the situation of *being* speaking can hardly be caused by an arriva that occurs after it has begun. Such an arrival could only plausibly caus something like the *beginning* of speaking.

(39a) When the guest of honour arrived, the chairman was speaking.
(39b) ?When the guest of honour had arrived, the chairman was speaking.

On such an account, the reference time set up by both past tensed *and* perfec *when* clauses will be something like the 'consequent state' of the event i question. And the reference relation will similarly not be purely temporal, bu will have to do with the main clause's being a consequence of the event in th subordinate clause. Very often, of course, an event which is a consequence o

another event occurs *just after* that event. But such is by no means always the case, either for perfect or for simple *when* clauses, as the following examples will show:

(40) When Fred { had finished / finished } the course, did he { take the exam? / get the degree? / get a job? }

It appears to make very little difference here whether the subordinate clause is in the perfect or not. (There is nevertheless one crucial difference, which will be discussed below.) And since all of the alternative main clauses are plausible consequences of the reference event, the fact that they would normally occur at very different intervals of time after it (and in the last case, after quite a long interval) does not seem to affect the reasonableness of the question.

If such an analysis is correct, once again a number of notorious problems become less puzzling. For one thing, the perplexing vagueness of the temporal intervals involved in the 'just after' meaning of *when* is understandable (see, for example, Ritchie, 1979, for a sensitive exposition of this problem). The temporal interval denoted will depend entirely upon the nature of possible consequential relations between the two events in question. Another problem for which the analysis seems to suggest a solution is the notorious tendency for the perfect to take over the function of the simple past tense, as it has in the evolution of modern spoken French, and for the reverse to happen, as in some American dialects of English in which the past tense does double duty for both perfect and simple past. Even apart from their inclusion in time adjuncts, references to past events nearly always involve some kind of causal or consequential relation—purely accidental temporal coincidences simply aren't as interesting and important to human purposes. When we refer to an event, we are therefore nearly always concerned with its consequences as well. It is not surprising that the simple past may usurp the consequent state-defining function of the perfect, nor that the perfect may take over the more purely temporal function that is usually assumed to be primary to simple tense.

Unfortunately, the account given above does not exhaust the complexities of the perfect in *when* clauses. For of course there *is* a difference in meaning between a perfect *when* clause and the corresponding *when* clause with simple past tense. For example, the following is a perfectly unremarkable statement:

(41) When Jane spilled the coffee, Fred cleaned it up.

But the following is most unusual:

(42) ?When Jane had spilled the coffee, Fred cleaned it up.

What is odd about (42) is that it seems to carry the implication that the

spilling of the coffee was *predicted* by the speaker, perhaps because it was pa
of an intended or planned sequence. The implication is a curious one to mak
of such an event. It can be exposed even more clearly by contradicting it wit
an adverb like *accidentally* or *suddenly*: the addition makes the sentence eve
less acceptable:

(43) ??When Jane had accidentally spilled the coffee, Fred cleaned u
the mess.

(Of course there is nothing wrong with such a proposition as a main clause:

(44) Jane had accidentally spilled the coffee.

The distinction brought out above was also latent between different version
of sentence (40).)

Since the distinction has once again to do with the role of the complemer
event in an overall plan or logical sequence, and since this idea has bee
associated both with the perfect itself *and* with the connective *when*, th
question arises as to which of these two entities gives rise to it here. Th
answer is that it stems from the *when*, not from the perfect. To show this, it i
necessary to step beyond the confines of reference to past events, and t
consider for a moment the meaning of *when* clauses involving present (o
rather, non-past) tense.

3.2 Reference to non-past time

A simple clause in the so-called present tense, with or without an auxiliary
most basically refers to the time of utterance.

(45a) I win!
(45b) The fish is eating the bait.
(45c) I have crossed the bar.

(As before, other uses of the present tense, such as the 'historic present', ar
ignored here.) All of the earlier remarks concerning the meanings of th
auxiliaries in main clauses and the anaphoric nature of tense appl
unchanged, with the single provision that the temporal referent to which th
present tense most basically refers to the instant of the time of utterance.

However, in a *when* time adjunct, a present tensed clause apparently refer
to anything *but* the time of utterance:

(46a) When I win, I shall buy champagne for everyone.
(46b) When the fish is eating the bait, I shall shoot it.
(46c) I hope to see my pilot face to face, when I have crossed the bar

(Again, the meaning of *when* corresponding to *whenever*, seen in *When I tak
my sugar to tea I'm as happy as I can be*, is not considered here.) What all o
these *when* clauses seem to share, regardless of their auxiliary, is the idea c

the speaker's *certain prediction* of the proposition in question, whether or not he is correct in that prediction.

The idea of prediction invoked above is exactly the same as that which was needed to express the meaning of a past perfect *when* clause. The above sentences imply that the time at which the predicting is done is the present reference time (that is, the time of utterance). They also imply that the predicted situation is later than the reference time (that is, in the future). But certain past tensed clauses, including clauses in the past perfect, also denote situations. And the time at which the predicting is done is again the reference time, albeit the *past* reference time—if one has not been established then a past perfect *when* clause simply isn't acceptable. And the predicted perfective situation itself—that is, the consequent state of the event in question—is again to be found later than the reference time.

In fact it seems that *all when* clauses which include a clause denoting a *situation*, as opposed to an event (as defined in Section 1.5 of this paper, and in Steedman, 1977), imply that the speaker predicts or predicted the situation in question. For example, stative verbs in past tensed *when* clauses seem to behave very much like the perfect, for example displaying the same incompatibility with situation-type main clauses that was noted in example (39b):

(47a) When I knew the answer, I immediately phoned the Grange.
(47b) ?When I knew the answer, Fred was telephoning the Grange.

Even past progressive *when* clauses (which are also defined as situations) seem to share this property, although the effect is a subtler one, and was glossed over in the earlier discussion.

The idea of *prediction* is not unrelated to the idea of logical *consequence* invoked earlier, so we must be careful to distinguish them. It will be recalled that, whereas a simple past tensed main clause, such as *she won*, demands a prior temporal referent for its past tense, a simple past tensed *when* clause does not. The *when* clause is rather used to set up a *new* reference point, and to over-write any prior one. However, the 'predictive' *when* clauses, including the perfect, *do* require a previously established reference point, and, like main clauses, cannot be used without one. One may begin a conversation with *When Ann came to stay*, . . . (provided the hearer can identify the occasion in question), but may not *begin* with *When Ann had come to stay*, ... The reason is that the latter demands a reference time at which it could be predicted that the person in question *would* come to stay (or at least attempt to do so). It is only if this condition is satisfied that the usual process associated with a *when* clause can take over, and the consequent state in question can be found.

Thus we distinguish *two* components to the idea of cause and consequence which has so bedevilled the above discussion of the temporal categories. The perfect denotes the state of affairs that is *consequent upon* the event which the

perfect dominates. On the other hand, the connective *when* with a situation a its complement seems to mean that the speaker can or could *predict* tha situation. Since the most common basis for a prediction is that one knows th chain of causes and consequences of which it is a part, it is perhaps no surprising that these two aspects of temporal meaning, which are logicall quite distinct, interact in such a complex fashion.

It might seem that this idea of predictability at a reference time, invoked t explain the behaviour of perfect *when* clauses, considerably complicates th idea of reference time itself. It is true that the notion that has been used so fa according to which the reference time of Reichenbach is represented as reference event or 'window' on the time-line (together with the referenc relation), will have to be elaborated once more. However, it will becom apparent that the elaboration in question is exactly what is needed in order t explicate the further problem of the 'consequential' meaning of *when* clause with simple past tense, originally introduced in example (2b).

3.3 When and the perfect

The extension to the theory that is implied by the preceding observations i simple in principle but complex in detail, and will be more fully develope elsewhere. The basic apparatus, consisting of a history, a data base describin the state of the world at any given instant, together with a set of housekeepin routines for the management of the data base, plus a body of world know ledge defined as inference procedures is still all that is required. However, th nature of the information represented in the history needs to be elaborated In particular, it is no longer going to be adequate to represent the history o events as the single time-line implied in the preceding discussion. It will rathe be necessary to represent it as comprising *several* time-lines, each associate with a single causal or consequentially related sequence of events leadin towards the satisfaction of a particular goal, or intention. These sequence may from time to time intersect or diverge, and may be nested one within th other, the nested sequence representing the steps undertaken in achieving sub-goal of the higher sequence. This representation has more of the charac ter of a railway marshalling yard than the single main line of the earlie account. It embodies the idea that it is only events that are consequentl related that necessarily have well defined temporal relations in memor Purely coincidental relations in time are less useful, and may be only vaguel defined. The linguistic categories under discussion reflect implicitly such a organization of episodic memory, which is closely related to the notion of script or plan advanced by Schank & Abelson (1977).

Consider, for example, the history of this type that is represented in Figur 5, which corresponds directly to a data structure in the program. This histor

might be paraphrased as follows:

'John, in order to compute the 99th prime number, logs on to the system, edits the program which he needs, runs the program, and logs out again. Meanwhile, Betty, in order to edit her own program, logs on at the same time as John and begins her edit. At a point during the time that John is running his program, Betty stops editing, and logs out. Moreover, the history represents the fact that it is John's starting to run that for some reason causes Betty to stop her work and sign off' Finally, while all this is going on, Ann, in order to print a program, signs on, prints it, and signs off at the same time as Betty.'

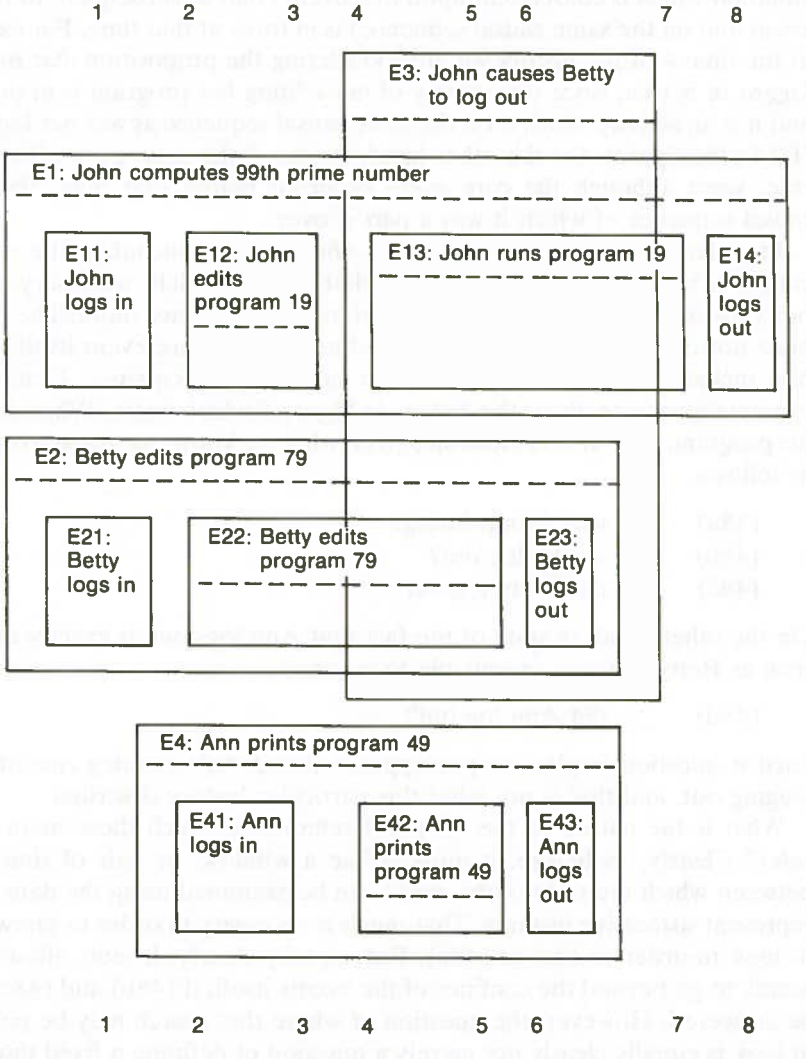


Figure 5 A 'history' of the model world showing causal sequences

Such a history is of course extremely simplified, for purposes of exposition For example there is no representation of *why* John's actions cause Betty to stop what she is doing nor of the fact that John's editing *enables* his running nor of the fact that Betty's editing is an incomplete period, or in Vendler's terms, an 'activity', unlike John's. In a more complete simulation these facts would be represented either in the history or in more general knowledge about the world. However, the example will serve the present purpose.

The definition of the perfect is straightforward in terms of such a representation. The perfect of a core event is true at some time if some event or situation which is consequent upon that event (that is, subsequent to the core event and on the same causal sequence) is in force at that time. For example at the time 4 of the history we are considering the proposition *that Betty has logged in* is true, since the activity of her editing her program is in progress and it is an activity which is on the same causal sequence as was her logging in (E2 in the figure). On the other hand, at time 7 the same proposition is no true, since although the core event occurred before that time, the entire causal sequence of which it was a part is over.

In order to explicate the effect of *when* clauses, including the so-called causal variety, and those including auxiliary *have*, it will be necessary to revise our view of Reichenbach's temporal reference point once more. The reference must not only include the 'window' defined by the core event itself. It must also include subsequent events in the same causal sequence. Consider for example questions about the history in Figure 5 which begin 'When John ran his program, . . .'. It is reasonable, given what we know, for these to continue as follows:

(48a) . . . , was Ann printing?
(48b) . . . , did he log out?
(48c) . . . , did Betty log out?

On the other hand, in spite of the fact that Ann logs out at exactly the same time as Betty, it is *not* reasonable to go on

(48d) . . . , did Ann log out?

Such a question implies or presupposes that John's running *caused* Ann's logging out, and that is not what this particular history describes.

What is the nature of the temporal referent to which these main clauses refer? Clearly, as before, it must define a window, or pair of time points between which the state of the world can be examined using the data base to represent successive instants. That much is necessary in order to know where to look in order to answer (48a). But, equally clearly, it must allow for the search to go beyond the confines of the events itself, if (48b) and (48c) are to be answered. However, the question of where that search may be permitted to look is equally clearly not merely a question of defining a fixed interval or

time, not even one whose extent is allowed to depend upon the character of the reference event. Any purely temporal interval which allows the program to see as far ahead as Betty's logging out is going to allow it to see Ann's as well. It is therefore clear that the temporal referent must include some note of the particular sub-history upon which the event itself is found. The search later in the history for the main clause event must only take account of events—like John's and Betty's logging out—which are causally related to the reference event. It must be blind to all others.

We may therefore think for the moment of the temporal referent as a pair of points on the time-line as before, plus a note of the parent sub-history or sub-histories on which the reference event occurred. But how *far* along the parent paths is the search to be allowed to proceed? Obviously, it may not examine any *earlier* events on the parent paths than the reference event. It might appear that all we need is to search as far as the *next* event on the parent path(s). However, it will be recalled that certain events (such as the repetitions discussed in Section 1) may be compound. There is therefore no simple way to define such a scope. The current program therefore allows the search for main clause events to 'see' all events later in the causal sequence on which the core event is found.

With the new representation of the episode, the perfect in a *when* clause has exactly the same meaning as it does in a main clause. For example, if the *when* clause had been 'When John had run his program . . .', the referent that would have been set up would simply be a period comprising all instants at which the perfect itself was true—that is, all instants subsequent to the core event at which some event or situation arising from the same causal chain were in force. In order to express what has been referred to as the 'predictive' quality of the perfect *when* clause, it is clear that the search for these instants should be conducted with respect to an established temporal referent, rather than with respect to the whole episode. The resulting new temporal referent is therefore very similar to the one established by the related simple tensed *when* clause, except that it does not include the core event, but *only* its consequential state. Hence the puzzling fact that sentences (49a) and (49b) below mean something very similar, while sentences (49c) and (49d) do not is explained—cf. sentences (38) and (39) above:

(49a) When John ran his program, he logged out.
(49b) When John had run his program, he logged out.
(49c) When John ran his program, he was computing the 99th prime.
(49d) ?When John had run his program, he was computing the 99th prime.

Two further aspects of the meaning of *when* clauses must be mentioned. First, when the main clause is an event-description and the causal relation is presupposed, it is also presupposed that the relation is direct—that is, that the

main event comes *next* on the path. This fact must be checked as part of the reference *relationship*[7]. Secondly, none of the above searching beyond the bounds of the original reference event is allowed in the case where the main clause is of the state-like 'situation' variety, nor do these carry any connotations of causation. It therefore follows that in the case of stative main clauses the search should be able to 'see' *all* the happenings in the history but should not proceed beyond the limits of the core event. That is to say that, for present purposes, *when* sentences with situation main clauses are very like the corresponding *while* sentences. It will be noted that such an account fails to explain the fact that most (but not all) sentences which have progressive or perfect main clauses with a perfect *when* clauses are anomalous (cf. Figure 1). That is to say that the program just described will produce the answer 'Yes' to the following questions about the history of Figure 5:

(50a) ?When John had run his program, was he computing the 99th prime?

(50b) ?When John had run his program, had he logged in?

However, not all such sentences are anomalous. In fact, they are acceptable just in case the imperfective or perfective situation described by the main clause is indeed a direct consequence of the core event of the *when* clause—for example:

(51a) When John had run his program was he still computing the 99th prime?

(51b) When John had run his program, had he finished computing the 99th prime?

However, at present, the program will accept all such sentences. The distinction in acceptability between (50) and (51), which appears to be intimately involved with further questions concerning the aspectual adverbials and verbs which appear in the latter sentences, will require further refinements to the definition of the consequential relation and its representation in the program.

To summarize this section: in order to account for the interaction of the perfect and causation in *when* clauses, a further elaboration of the concepts of episodic memory and reference time to include the idea of logical sequence of events has been necessary. Within this framework, the meaning of *when* clauses can be defined as follows. If the *when* clause is of the 'situation' variety, then the search for the new temporal referent is to be conducted within an establishing referent. If the *when* clause is of the 'event' variety then the whole episode is searched. If the *main* clause is a situation, then the search for that situation is confined to the scope of the core event, and the whole effect is rather similar to that of a *while* sentence. If the main clause is an event, then the search for that event includes the consequences of the core event in the *when* clause.

4 CONCLUSION

In the preceding sections of the paper a model has been outlined of the way people answer questions about episodes. The discussion has concentrated on the function of *while* and *when* clauses. By successive refinements of Reichenbach's (1947) original notion of the temporal reference point that is established by such clauses, it has been possible to account for certain apparent ambiguities of tense, and of the progressive and the perfect, as being ambiguities of reference, arising from a single sense. The relation of causal or consequential meanings to more purely temporal ones has been discussed. In particular, the intimate relation of both the perfect and the connective *when* with causation and prediction has been examined. The tendency of simple past tense and the perfect not only to appear ambiguous, but also to take on each other's roles, has also been explicated in terms of the model.

The model hinges upon the idea that memory for episodes is linearly ordered, by analogy with the temporal sequences that it represents. The functions of tense, the auxiliaries, and the time adverbials are to direct the hearer's attention to certain points in such a structure, and to move the shared point of attention up and down the time-line that such a memory emulates.

The story has been a complex one. The reason has been that at every turn the idea of causation has intruded into the simple localist paradise of purely temporal descriptions suggested by the theories of Reichenbach and Isard with which the account began. Indeed, it seems that episodic memory should not be thought of as a single linear ordering of events, but rather as being further structured into sub-histories of events which are related as successive elements in causal chains constituting the plans and intentions of participants in the episode. Several such sub-histories will typically be in progress at any one time. Certain of the time adverbials, like *while* adjuncts, express purely temporal relations between events, and apply across different causal chains. Others, like *when* adjuncts, will have more to do with relations of sequence *within* such chains.

It is perhaps worth concluding by attempting to identify the significance of the computer in the development of this model, and for the study of deixis and reference in general. Any phenomenon in natural language which depends upon the changing context of a conversation presents the theorist with the problem of formalizing processes of change in the situation referred to. Deictic and anaphoric reference, including such reference to events, depends upon such processes of change in the context of discourse. A computer program expresses very directly the processes that result when it is run on the computer. For such a process, the idea of a context corresponds closely to that of the changing state of the variables which the program accesses during the computation, as Isard (1975) has pointed out. Programs therefore offer a helpful notation for precisely those pragmatic aspects of reference that are

most intractable in non-procedural terms, and with which the meanings of th time descriptions considered here are intimately bound up.

NOTES

1. This work has continually been influenced by many discussions with Stephen Isar He, Gill Brown, Jeb Ellman, Orvokki Heinamaki, Wolfgang Klein, Chris Mellish Carlota Smith, and Cathy Urwin kindly read earlier drafts and made many helpfi suggestions. Earlier versions were presented to the Max-Planck-Gessellschaft confe ence on Spatial Deixis, Nijmegen, March 1978, the Psycholinguistics Summer Schoo Mulsjo, August 1979, and the Semantics Workshop on Events, Situations an Actions, Austin, October 1980. The research was supported by a grant for computa tion from the SSRC and a Visiting Fellowship from the Sloan Foundation held at th Center for Cognitive Science of the University of Texas at Austin.

2. The word *meaning* will be used throughout the paper in an intentionally vagu common-language sense to refer indiscriminately to all aspects of meaning. When it necessary to be more precise, such terms as *sense*, *reference*, and *denotation* will b used.

3. It should be remarked in passing that although a *when* clause is always evaluate before the main clause, and establishes the referent for its tense, it is not always th case that this referent endures for the tense of later 'naked' main clauses to refer t The setting up of an enduring permanent temporal referent seems always to b markedly by an intonation break, whether the relative clause precedes or succeed the main clause or is parenthetically embedded within the main clause as in

(i) John, when he saw the expression on my face, made an excuse and left.

A *when* clause which is not set off from its matrix by intonation, does not set up temporal reference point which outlasts the matrix sentence. An example is sentenc (ii b)of the following exchange.

(ii a) When John arrived, did Mary leave?
NO.
(ii b) Did Mary leave when Fred arrived?
NO.
(ii c) *Did Ann arrive?

Sentence (ii a) sets up the temporal referent of John's arrival, as usual. Had sentenc (ii c) followed immediately, it would have been understood as referring to the sam reference time. However, although the *when* clause of (ii b) sets the temporal referer for its main clause, it does not establish Fred's arrival as a *permanent* reference poin and so sentence (ii c) fails to refer to that time. (To make sentence (ii c) successfull refer to Fred's arrival, it would be necessary to include the word *then*, which explicitl refers to the most recently mentioned time, rather than to an established referenc time. *Then* has rather the effect that the phrase *at that time* has, and itself may set up new and enduring temporal referent.) What is more, sentence (ii b) seems to rende the reference point set up by (ii a) inaccessible to the temporally anaphoric tense c (ii c).

The above variety of functions that may be performed by *when* clauses are closel related to those involved in Halliday's (1967) constructs of theme and informatio Elsewhere, Steedman & Johnson-Laird (1978) have related semantics of theme an information in general to the same fundamental characteristic of the huma

language-understanding mechanism that is exploited here, namely that it is a left to right process (albeit one that is under a hierarchical control), in which as much interpretation as possible is done as *soon* as possible. However, the present discussion is limited, like that of Isard (1974), to temporal relative clauses which establish an enduring temporal referent, that is to say to those separated from their main clause by one or more intonation breaks.

4. It will be obvious that the notion of cause or consequence is a complex one. For example, two events are held to stand in this relationship if the former merely *enabled* the occurrence of the latter, as well as when it actually caused it. Schank (1975) provides one possible taxonomy of the varieties of logical sequence of events in episodes.

5. This analysis is not meant to imply that *no* events involving repetition are represented as a whole in people's histories of episodes. Events like bands playing and programs running are perhaps prototypically single, non-repeated events. But activities like *talking to Mary* are likely to be repeated *en bloc*, not as a lot of individual utterances, and would not behave like examples (27) and (29).

6. The current paper will not deal with progressives of 'achievements', such as

(i) John was winning the race

which designate a prospective situation of activity leading up to the core event. While space prohibits any discussion of them here (but cf. Vlach, 1977; Dowty, 1979) it seems likely that the notion of causal or consequential sequences of events which is involved in the treatment of the perfect will be crucial to the analysis of these and the associated 'imperfective paradox' as well.

7. It is not quite clear whether this fact is in the domain of semantics or pragmatics. This detail is not currently implemented.

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